TEMPERATURE DISTRIBUTION PATTERN IN NORMAL AND CANCER TISSUES: THE EFFECT OF ELECTROMAGNETIC WAVE

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Abstract **-Temperature distribution pattern on normal and cancer tissues caused by the Electromagnetic wave effect is presented in this paper. First, the pattern is modelled by using Bio Heat Transfer Equation and then the Galerkin Finite Element method is used to solve the equation via computer simulation. From the simulation results it can be shown that the temperature change on the cancer tissues is relatively constant and 0.4 °C higher than the change on the normal tissues. From this phenomenon it can be understood that the damage of the cell of the cancer tissues is greater than the damage of the cell of the normal tissues. Therefore it is possible to use the Hyperthermia technique with electromagnetic wave for cancer therapy. The simulation results can be also used to decide the control strategy for giving the dose energy of electromagnetic wave which is flowed out to the cancer tissues.**

Keywords-**Temperature, Cancer, Electromagnetic wave**

I. INTRODUCTION

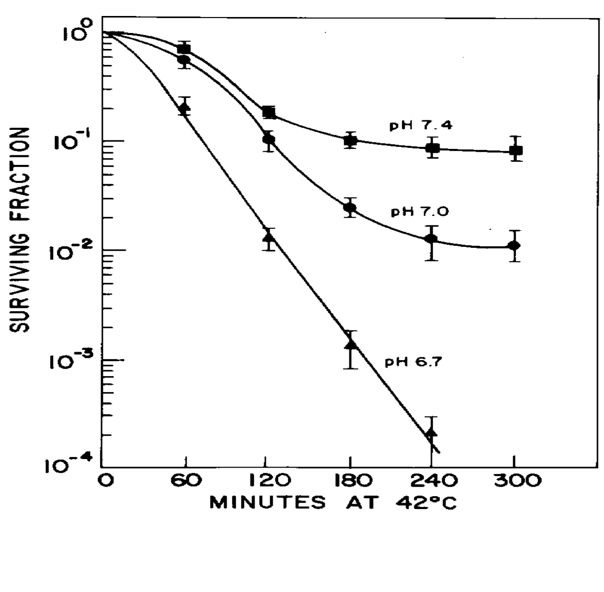
Several well-known methods of cancer therapy so far are radiotherapy, chemotherapy and surgical operation. In radiotherapy method – for example X-ray – cancer cells are killed by utilization of radiation ray through ionisation process of the cell. Drug is used in chemotherapy method, while in surgical operation method, the cancer cells are removed from the tissue by operation. Hyperthermia is one of the therapy technique by means of increasing the temperature of cancer tissue several degrees above normal body temperature (41 to 45 °C)

Several studies show that the roles of hyperthermia as radiosensitizing and chehmosensitizing agents are one of effective way for cancer therapy [1]. The positive impact of combination of radiotherapy - hyperthermia was studied by [2][3], and chemotherapy – hyperthermia by [4][5].

In general, the characteristic of cancer cell tissue has pH <7.4, lower than the normal one (pH>7.4). In consequence, oxygen and nutrition supply are low. Therefore, temperature of cancer tissue is easier to increase than the normal one. The relation between pH, heat energy exposed time and cell lethality influence (called as surviving factor) is shown in Figure 1. The treatment of hyperthermia on normal tissue causes the increase of 3 to 20 times than the normal blood flow. On the contrary, the same treatment to the cancer tissue causes only less than 2 times of the normal blood flow. It means that heat dissipation by blood flow on normal tissue is bigger than cancer tissue. Therefore it is easy to understand that for the same exposure, the damage of cancer tissue will be higher than the normal one [6].

To increase the tissue temperature, several energy transfer methods are used, namely mechanic-to-thermal energy transfer (ultrasound method), thermal-to-thermal (contact method) and electromagnetic-to-thermal method. In this paper will be discussed concerning effect of electromagnetic wave on biologic tissues.

Several stages are needed to determine



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Abstract

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pattern of temperature distribution caused by electromagnetic wave [7]; firstly is a model development to find Bio-Heat Transfer equation (BHT), that is derived with taking account the effect of internal factors such as conduction, convection (blood flow), electrical characteristic, and thermal characteristic of biological tissues; and external factors such as frequency of electromagnetic wave that used, distance of wave guide to surface of tissue, and power density of electromagnetic wave. Secondly, derive of Electromagnetic Wave Propagation (EWP) to determine electric field in biological tissues. And finally, is using Galerkin finite element method to solve the BHT and EWP.

Figure 1. Relationship between pH, time exposure and surviving fraction

II. THERMAL MODELLING

If external energy supplied to human body, energy balance in human body (Q) can be expressed by:

$$Q = Q_p + Q_m + Q_b \quad (1)$$

with

Q_p :Thermal absorbed by biological tissues (human body)
Q_b :Heat exchange with blood flow
Q_m : Metabolic heat generation

Using Fourier law (heat transfer through conduction) and rate of temperature change in human body affected by electromagnetic energy transfer, therefore Bio Heat Transfer Equation (BHT):

$$\rho_t\ c_t\ \delta T/\delta t = Q_p + Q_m + \nabla \bullet (k\nabla\ T).Q_b \quad (2)$$

where :

ρ_t = tissue density [kg/m³]
c_t = tissues heat capacity [J/kg °C]
k = thermal conductivity [W/m °C]
Q_p=tissue absorption rate from external source [W/m³]
Q_m=rate of metabolic heat generation [W/m³]
Q_b = rate of heat exchange with blood. [W/m³]

Under an assumption that the system at the steady state condition and the heat generated by metabolic process is ignored, the heat transfer affected by convection (blood flow):

$$Q_b = -\ m_b \rho_b\ \rho_t c_b\ (T - T_b) \quad (3)$$

Where are m_b is rate of blood mass and T_b is arterial blood temperature that inflow to zone treated. Because blood inflow to zone treated, initially at arterial temperature T_b that assumed equally to normal temperature of body, therefore T_b is zero. Meanwhile the heat absorbed by biological tissue is given by the following:

$$Q_p = \tfrac{1}{2}\ \sigma |E|^2 \quad (4)$$

With E is the intensity of the electric field and σ is the electric conductivity of the biological tissue. The BHT equation now become:

$$\nabla\bullet(k\nabla\ T) - \alpha\ T + \tfrac{1}{2}\ \sigma\ |E|^2 = 0 \quad (5)$$

with: $\alpha = \rho_t\ \rho_b\ c_b\ m_b$

In order to know pattern of the temperature distribution on the biological tissue, firstly intensity of the electric field to be computed using Maxwell equation as the following:

$$\nabla^2 E + \gamma^2 E = 0 \quad (6)$$

with:

$\gamma^2 = \omega^2\ \mu\ \varepsilon*$
γ = constant of propagation.
$\varepsilon*$ = complex permittivity

III. GALERKIN FINITE ELEMENT

The use of electromagnetic wave on the biological tissue will generate the electric field at the tissue. The intensity of the electric field is obtained by solving equation (6) and the Galerkin finite element method is used to solve equation (6) as the following. First, equation (6) is written as the following form.

$$\sum_{j=1}^{n} (\int w_j\ (\nabla^2 E + \gamma^2 E)\ dA = 0$$

Where w_j is the weighting factor; j is the number of element; and n is the number of the node. Since in the Galerkin finite element method the weighting factor is equal to the shape function (w=ϕ), the following matrix equation is obtained for each node.

$$[K]\,[E] = [D] \qquad (7)$$

with: $[K] = [A] + [B]$

$[A] = \int (\nabla\phi)^{T} (\nabla\phi)\, dA$;

$[B] = -\int \phi^{T} \gamma^{2} \phi\, dA$; $[D] = \int \phi\, (\nabla E)^{T} n\, dL$

Second, after the intensity of the electric field is obtained, then using the same method the temperature distribution pattern can be obtained through the solution of the matrix form of equation (5).

$$[K]\,[T] = [E] \qquad (8)$$

with : $[K] = [F] + [B]$; $[E] = [C] + [D]$

$[F] = \int (\nabla\phi)^{T} k\, \nabla\phi\, dA$; $[B] = \int \phi^{T} \alpha\, \phi\, dA$;

$[C] = \int \frac{1}{2} \phi\, \sigma\, |E|^{2}\, dA$; $[D] = -\int q^{T} n\, \phi\, dL$

Hence, the temperature distribution pattern as a side effect of using the electromagnetic wave on the biological tissue is obtained by solving equations (7) and (8) via simulation [8].

IV. RESULTS

The hyperthermia technique was simulated on the thigh tissue with the finite element grid as shown in Fig. 2 using the following parameters:

Time: 30 minute

Frequency: 915 MHz

The distance between the applicator and the object therapy (cancer zone): 1.5 cm.

Figures 3, 4 and 5 show the simulation results of the real part, imaginary part and the magnitude of the electric field as a function of the node, respectively. It should be noted that the nodes 1 ~ 13 represent the skin layer, the nodes 14 ~ 25 represent the boundary between the skin and the fat layers, the nodes 25 ~ 63 represent the fat layer, the nodes 39 ~ 46 show the muscles, the nodes 47 ~ 49; 56 ~ 58; 65 ~ 66 represent the bone and the nodes 67 ~ 80 represent the cancer tissue.

From the simulation results, it can be seen that there is a significant change of the real part, the imaginary part and the magnitude of the electric field at the nodes 1 ~ 10 (the skin layer). This is caused by the big enough absorption of the external energy at the skin layer. Meanwhile, the electric field at the node 60 ~ 80 (the cancer tissue) is relatively homogenous and constant.

On the other hand, the temperature distribution as a side effect of electromagnetic wave is shown in Fig. 6. From this figure, it can be seen that the temperatures at the skin layer and at the boundary between the skin and the fat layers change very fast. The highest temperature occurred at these layers. Meanwhile, the changing of the temperatures at the fat, the muscle and the bone layers are not so high, moreover, almost constant. It means that the skin layer and the boundary between the skin and the fat layers are very sensitive for the heat over-accumulation that might cause burning these tissues.

It also can be seen from Fig. 6 that the increasing of the temperature at the cancer tissue is relatively constant and higher than the increasing at the bone layer (the nodes 47 ~ 66). It means that the temperature at the cancer tissue is relatively homogenous and it makes possible for occurring the damage of the tissue.

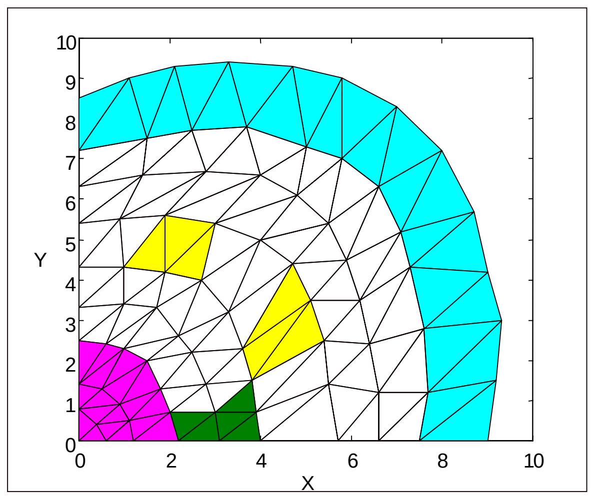

Figure 2. Grid of finite element on thigh tissue

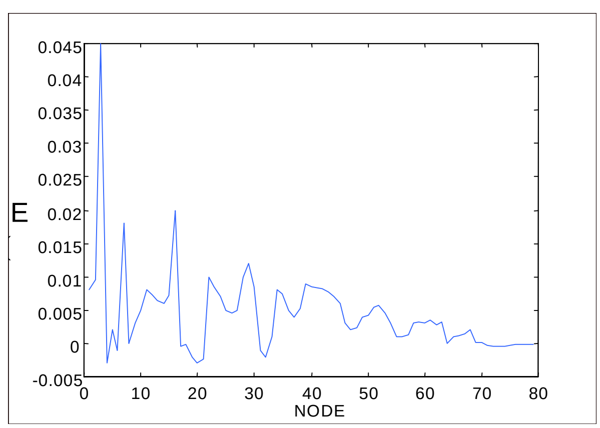

Figure 3. Real part of Electric field

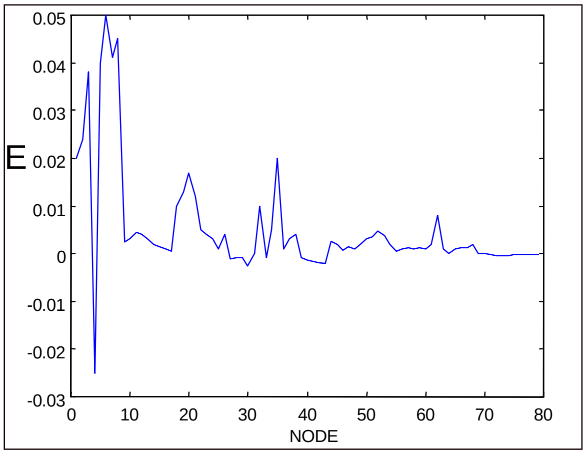

Figure 4. Imaginer Part of Electric Field

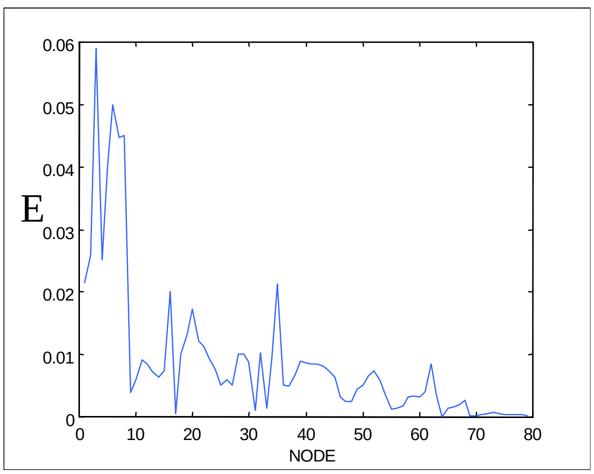

Figure 5. Magnitude of Electric Field

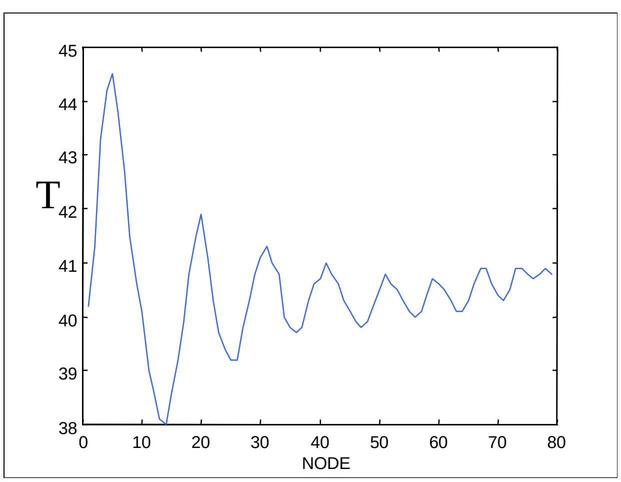

Figure 6. Temperature Distribution effect of Electromagnetic wave

V. CONCLUSION

The temperature distribution pattern of the hyperthermia technique is affected by several factors such as: conduction, convection (blood flow), thermal and electrical properties of the biological tissue, energy absorption of the biological tissue, the electrical field that occurred at the biological tissue and the thermal regulation system in biological tissue. On the other hand, the electric filed at the biological tissue is affected by several factors such as: the distance between the applicator and the biological tissue, the shape of the applicator, the frequency of the electromagnetic wave, conductivity and permittivity of the tissue.

The high enough temperature change (about 44.8 °C) occurred at the boundary between the skin and the fat layers. This high temperature change might burn the tissue. Therefore a protocol for therapy that could reduce the temperature change is needed.

The increasing of the temperature at the cancer tissue is relatively constant and higher (about 0.4 ° C) than the increasing at normal tissue. This phenomenon means that the heat absorption rate at the cancer tissue is greater than the rate at the normal tissue, so that the possibility of occurring the cell destruction at the cancer tissue is greater than the possibility at the normal tissue. The results provide a justification of using the hyperthermia technique for cancer therapy.

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